NEURO MODELLING AND VIBRATION CONTROL OF FLEXIBLE RECTANGULAR PLATE STRUCTURE

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ABSTRACT

The demand for soft computing techniques in the modeling and control of dynamic system has increased in recent years especially for flexible structures. Flexible plate structures are extensively used in many space applications, however this type of structure leads to high vibration problems. The aim of this investigation is to modelling and control of two dimensional flexible plate structures. This will involve an identification system including least squares, recursive least squares, and neural networks within an active vibration control framework. A thin rectangular plates with all edges clamped is considered. A simulation algorithm characterising the dynamic behaviour of the plate is developed through a discretisation of the governing partial differential equation formulation of the plate dynamics using finite difference methods. The simulation algorithm thus developed and validated forms a suitable test and verification platform in subsequent investigations for development of vibration control techniques for flexible plate structures. The design and analysis of an active vibration control (AVC) system utilizing conventional and soft computing methods with single-input single-output AVC structure is presented to suppressing the vibration of the flexible plate structures. Finally a comparative performance of the algorithm in implementing AVC system using recursive least square (RLS), Multilayer perceptron neural networks (MLP-NN) and Elman Neural networks (ENN) is presented and discussed.

ABSTRAK

Sejak kebelakangan ini permintaan ke atas teknik perkomputeran dalam pemodelan dan pengawalan sistem dinamik telah meningkat terutamanya bagi struktur-struktur yang fleksibel. Struktur plat nipis yang fleksibel ini banyak digunakan di dalam pelbagai aplikasi, namun begitu struktur jenis ini lebih cenderung kepada masalah getaran yang kuat. Tujuan utama projek ini adalah untuk membina model dan mengawal getaran struktur segiempat tepat plat nipis yang fleksibel dengan menggunakan sistem pengenalan termasuk *Least Squares* (LS), *Recursive Least Squares* (RLS) dan *Neural networks* (NNs). Satu algoritma simulasi yang mengambarkan ciri-ciri dinamik segiempat tepat plat nipis dibentuk melalui pemecahan persamaan pembezaan separa plat dengan menggunakan kaedah pembezaan terhingga. Algoritma simulasi yang telah dibentuk ini diuji dengan ujian-ujian pengesahan yang sesuai untuk memastikan kesahihannya dan dapat digunakan sebagai platform untuk pembinaan teknik pengawalan getaran (*Active Vibration Control*) segiempat tepat plat nipis. Rekaan dan analisis keatas sistem aktif pengawal getaran dibina dan dianalisis dengan menggunakan RLS dan NNs untuk menghapuskan getaran yang wujud terhadap stuktur segiempat tepat plat nipis yang fleksibel ini. Akhir sekali perbandingan prestasi diantara LS, RLS dan NNs termasuk *Multilayer Perceptron Neural Networks* (MLP-NN) dan *Elman Neural Networks* (ENN) dalam perlaksanaan sistem aktif pengawal getaran dibentangkan dan dibincangkan dalam projek ini.

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w	-	lateral deflection in the z direction
Qx, Qy	-	dynamic shear forces per unit length
Mx, My	-	moments per unit length
Mxy	-	twisting moment per unit length
ρ	-	the mass density per unit area
h	-	thickness of the plate
$\partial v / \partial x, \partial v / \partial y$	-	angular velocities
$\frac{\partial^2 \mathrm{w}}{\partial \mathrm{t}^2}$		acceleration in the z direction
$\rho h \frac{\partial^2 w}{\partial t^2}$	-	inertia force
$\sigma_x, \sigma_y, \sigma_z$	-	the stresses in a plate
$\varepsilon_x, \varepsilon_y, \varepsilon_z$	-	the strains in a plate
E	-	modulus of elasticity
μ, v	-	Poisson's ratio
$D = \frac{E}{1-\mu^2} \frac{h^3}{12}$	-	flexural stiffness of the plate
τ_{xy}, τ_{yx}	-	shear stress
G	-	shear modulus
ξ and ζ	-	components of the displacement of a volume element in x and y direction
$\partial \xi$ and $\partial \zeta$	-	rotations in x and y direction
z	-	moment arms
q (x,y,t)	-	the transverse external force, with dimensions of force per unit area

x	-	the independent continuous variables
$\Delta x,\ \Delta y$	-	indicated the distance between mesh lines in x and y direction
i	-	the value of variable at each of grid points
t	-	time
a	-	width of the plate in x-direction
b	-	length of the plate in y-direction
n	-	sections in x direction
m	-	sections in y direction
$w_{i,j,k+1}$	-	the deflection of grid points i = 1, 2,…, n and j = 1, 2,…, m at time step $k+1$
$W_{i,j,k},\ W_{i,j,k-1}$	-	the corresponding deflections at time steps k and $k-1$
A	-	a constant n×n matrix
F	-	an $n\times1$ matrix known as the forcing matrix
B	-	a scalar constant related to the time step Δt and mass per unit area, ρ of the plate
I	-	Second Moment of Inertia
$\lambda = \omega a^2\left(\sqrt{\rho/D}\right)$	-	the parameters
ω	-	the frequency in rad/s
$y(t)$	-	the system output at time t
$u(t)$	-	the system input at time t
$e(t)$	-	white noise at time t
$A(z^{-1}), B(z^{-1}), C(z^{-1})$	-	polynomials with associated parameters of autoregressive, exogenous and moving average parts
z^{-1}	-	the back-shift operator
β	-	parameter vector of LS estimation
$f(\cdot)$	-	a non-linear function
$\varepsilon(t)$	-	the prediction error sequence
$\phi_{u\varepsilon}(\tau)$	-	the cross-correlation function between $u(t)$ and $\varepsilon(t)$
$y = \Phi(\sum_i X_i W_i + W_0)$	-	a mathematical description of a neuron

$x = [x_1, x_2, \ldots.. x_N, 1]^T$	-	the input vector
$w=[w_1, w_2, \ldots.. w_N, w_0]^T$	-	the weight vector of a neuron
O_k	-	output values at the output layer
O_j	-	output values at the hidden layer
O_i	-	output values at the input layer
w_{kj}	-	a connection weight from unit j at the hidden layer to unit k at the output layer
w_{ji}	-	a connection weight from unit i at the input layer to j at the hidden layer
θ_j , θ_k	-	the biases
$f(x)$	-	is an activation function
$f(x) = \frac{1}{1+e^{-x}}$	-	a sigmoid function
$f(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}}$	-	a tanhyparabolic function
$E_p = \frac{1}{2}\sum_k (\tau_{pk} - O_{pk})^2$	-	a squared error function
τ_{pk}	-	desired output
O_{pk}	-	the corresponding actual output
δ_k	-	the error signal from the NN output to the hidden layer
δ_j	-	the error signal from the hidden layer to the input layer
η	-	the learning rate
r_e	-	a distance of detector relative to the primary source
r_f	-	a distance of secondary source relative to the detector
r_g	-	a distance of observation point relative to the primary source
r_h	-	a distance of observation point relative to the secondary source
E	-	transfer function of the paths through r_e
F	-	transfer function of the paths through r_f

G	-	transfer function of the paths through r_g
H	-	transfer function of the paths through r_h
M	-	transfer characteristics of the detector
C	-	transfer characteristics of the controller
L	-	transfer characteristics of the secondary source
U_D	-	primary signal at the source locations
U_C	-	secondary signal at the source locations
Y_D, Y_C	-	corresponding signal at the observation point
U_M	-	detected signal
Y	-	observed signal.
Q_o	-	the equivalent transfer function characterised by $U_C = 0$
Q_1	-	the equivalent transfer function characterised by $U_C \neq 0$

LIST OF ABBREVIATIONS

FDM	Finite Difference Method
BEM	Boundary Element Method
DQ	Differential Quadrature Method
FEM	Finite Element Method
PDE	Partial Differential Equations
DSC	Discrete Singular Convulation
MLS-Ritz	Moving Least Squares Ritz Method
FFT	Fast Fourier Transforms
LS	Least squares
RLS	Recursive Least Squares
PEM	Prediction Error Method
LMS	Least Mean Squares
GA	Genetic Algorithm
NNs	Neural Networks
ANFIS	Adaptive Neuro-Fuzzy Inference System
MLP-NN	Multilayer Perceptron Neural Network
ENN	Elman Neural Network
RBF-NN	Radial Basis Function Neural Network
RNN	Recurrent Neural Networks
OSA	One step-ahead prediction
ARX	Auto Regressive with exogenous inputs
NARX	Non-linear Auto Regressive with exogenous inputs

ARMAX	Auto Regressive Moving Average with exogenous inputs
NARMAX	Non-linear Auto Regressive Moving Average with exogenous inputs
AVC	Active Vibration Control
SISO	Single-Input Single-Output
SIMO	Single-Input Multi-Output

CHAPTER 1

INTRODUCTION

1.1 Overview

Flexible structures are extensively used in many space applications. Plates, beams, frames and shells are basic elements for flexible structural analysis and are of great practical significance to civil, mechanical, marine, aerospace engineering and other areas of practical interest, such as slabs on columns, satellites flexible manipulators, printed circuit boards or solar panels supported at a few points.

The flexible plate structures are used now in diverse applications leads to the demand of having reliable, light and efficient flexible structure. The plate materials are now thinner, lighter and larger than before. However, thin, light and large structure leads to high vibration. A vibration of flexible structures cause reduced system effectiveness, structural fatigue and human discomfort. With their potential applications and problems, the vibration of plates and with complex boundary conditions has received considerable attention from researchers. The vibration of plates has been studied extensively since

1787, due to its important in the design of plate structures and many of the important studies in this field were documented in Leissa's monograph (Zhou and Zheng, 2005). However, to control the vibrating of plate is complicated due to the highly non-linear nature of dynamics of the system which is involving complex processes. Accordingly, there is a growing need for developing suitable modeling and control strategies for such system (Mat Darus and Tokhi, 2003).

Various analytical and numerical methods have been developed to investigate the vibration behavior of plates. Although analytical methods are important to give an insightful understanding of the vibration behavior and to benchmark frequencies of plates, numerical methods are preferred in the vibration analysis of plates due to the fact that most of the plates vibration problems do not admit analytical solutions. The reason is a part from a few analytically solvable cases, there is no general solution for the static analysis of plates and therefore, numerical simulation is one of the major approaches. The performance of a numerical simulation depends crucially on the computational method employed. Typically, structural analysis computations are accomplished by using either global or local methods. Global methods are highly accurate but are often cumbersome to implement in dealing with complex geometries and non- conventional boundary conditions. For example, a global method may be found to converge slowly due to a mixed boundary condition which induces a large local stress concentration. In contrast, local methods are easy to implement for complex geometries and discontinuous boundary conditions. However, the accuracy of local methods is usually very low. For example, it may have convergence problems for the prediction of large eigenvalues in a vibration analysis (Hou et. *al*, 2005).

A variety of computational methods have been employed successfully for plate analysis. These include the Superposition method, Levy approach, point collocation method, finite difference method (FDM), Boundary element method (BEM), differential quadrature (DQ) method, Rayleigh method, Ritz variational methods, Meshless methods to the finite strip method and the finite element method (FEM) (Zhou and Zheng, 2004). The finite difference method (FDM) and the finite element method (FEM) are widely used numerical techniques. These methods are classified as domain methods, in that the engineering system is analyzed either in terms of discretized finite grids (FDMs) or finite elements (FEMs) throughout the entire region of the system.

To obtain an accurate model of the plate structures in order to control the vibration of a plate efficiently is crucial. An accurate system will result in the realisation of satisfactory control. A model can be created using a partial differential equations (PDE) formulation of the dynamics of the flexible plate to representing the dynamics behaviour of the plate (Mat Darus and Tokhi, 2003). Among the most important of the numerical approaches for modelling flexible plate problem such as finite element method (FEM), finite difference method (FDM) and boundary element method (BEM) have previously been considered (Ugral, 1999). These techniques eventually require the solution of a system of linear algebraic equations. Such calculations are commonly performed by means of a digital computer employing matrix methods. The computational complexity and consequent software coding involved in both the FEM and BEM constitute major disadvantages of these techniques, especially in real-time applications. However, in order to makes the technique more suitable in real-time applications to reduced amount of complexity in computation involved in FDM (Mat Darus and Tokhi, 2003). Moreover, it is to be noted that the FDM is simple, versatile, suitable for computer and programmable desk calculator use, and the results in acceptable accuracy for most applications involving a uniform structure, such as plate considered here. Thus, FDM is used to obtain an efficient numerical method of solving the PDE formulation of the dynamic of the plate by developing a finite-dimensional simulation of flexible plate through discretisation of the PDE in both the time and space coordinates.

The MATLAB software is used to implementation the algorithm and it allows application and sensing of a disturbance signal at any mesh point on the plate. Such a provision is desirable for the design and development of active vibration control techniques for the system (Mat Darus and Tokhi, 2003). Then, a MATLAB finite difference method (FDM) was developed to perform subsequent system identification algorithm simulations. System identification is extensively used as a fundamental requirement in many engineering and scientific applications. The objective this system is to find exact or approximate models of dynamics system based on observed inputs and outputs. Once a model a physical system is obtained, it can be used for solving various problems such to control the physical system or to predict its behaviour under different operating conditions (Shaheed and Tokhi, 2001). A number of techniques have been devised by researchers to determine models that best describe input-output behaviour of a system. Parametric and non-parametric identification are two major classes of system modeling techniques.

In the case of non-parametric models, neural networks (NNs) are commonly utilised. Neural networks are extensively used in many engineering applications. In dynamic systems application, it can be easily combined with the natural system dynamics and an intelligent machine. Application of neural network for identification and control of systems has gained significant momentum in recent years (Shaheed and Tokhi, 2001). Neural networks (NNs) originated in an attempt to build mathematical models of elementary processing units of the brain and the flow of signals between these processing units. After a period of stagnation, these formal models have become increasingly popular, with the discovery of efficient algorithms capable of fitting them to data sets. Since then, neural nets have been applied to build computerized architectures that can approximate non-linear functions of several variables, and classify objects. A neural net is nothing more than a sophisticated black box non-linear model that can be trained on data.

1.2 Statement of Problems

The aim of this project is to investigate and develop the Neuro modeling and vibration control of a two-dimensional flexible rectangular plate structure using neural networks. A thin rectangular plate with all edges clamped is considered. By understanding the dynamic characteristics and mode classification of the rectangular plates, it will be a useful tool to assist engineers for development of active vibration control strategies for flexible plate structures to avoid vibration.

A simulation algorithm characterising the dynamic behaviour of the plate is developed through a discretisation of the governing partial differential equation formulation of the plate dynamics using finite difference methods. An important aspect of the work is to implement this algorithm on the computer using the MATLAB. The MATLAB software is used to implementation the algorithm and it allows application and sensing of a disturbance signal at any mesh point on the plate. MATLAB was chosen as the programming language for this work; since (1) MATLAB which facilitates program development with excellent error diagnostics and code training capabilities, (2) Advanced software features such as dynamic memory allocation and interactive error tracing reduce the time to get solution, and (3) The versatile but simple graphics commands in MATLAB also allow easy to create graphs and surface plots. The investigation is accomplished by varying the width over the length ratio of the plate. The dynamic behaviour characterization of the system in performance of the developed algorithm is assessed in comparison with previously reported results by using various other methods. Therefore, the data obtained from the first part of work will be used to develop and control the neural networks model. This will involve a neural networks algorithm within an active vibration control framework.

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